APPENDIX J
ASSESSMENT OF POTENTIAL SEDIMENT RISK FROM CULVERT FAILURES

Prepared by Lolo National Forest with additions by Montana Department of Environmental Quality

Introduction

Spatial analysis of roads and stream GIS layers indicates 895 road-stream intersections within the St. Regis watershed. Due to limited mapping accuracy of GIS layers, many of the 895 crossings are spurious. Based on field verification, there are more realistically about 621 stream crossings in the St. Regis watershed. In 2002, 247 of these culverts were screened as part of a Forest-wide inventory of culvert fish passage capabilities, and a formal survey was completed for a sub-sample of 124 culverts on fish-bearing streams. Fish-bearing streams were defined as those with intermittent or perennial flow and less than 25% gradient. Surveyed culverts represent approximately 20% of the 621 stream crossings in the St. Regis watershed. Culverts were surveyed in each of the St. Regis River tributary watersheds (**Table J-1** and **Figure J-1**). Surveyed culverts are all located on roads within the National Forest boundary or on roads outside the National Forest boundary but maintained by the Forest Service. Data collected include culvert dimensions, average fill height, road width, bankfull width, and other parameters.

Table J-1. Stream crossing culverts on fish-bearing streams in St. Regis watershed surveyed in 2002 as part of culvert fish passage analysis

HUC 6 No. (1701020408xx)	HUC 6 Name	Number Surveyed	Estimated number of crossings in the watershed	Percent of culverts measured in the watershed
04	Big Cr	9	49	18
06	Deer Cr (St. Regis)	6	16	38
11	Little Joe Cr	11	120	9
12	Lower St. Regis_Mullan	3	159	2
02	Packer Cr	9	54	17
05	Savenac Cr	4	18	22
03	Silver_Timber	13	62	21
08	Twelvemile Cr	29	166	17
07	Twin Cr_St Regis	3	38	8
10	Twomile Cr	9	47	19
01	Upper St. Regis	22	100	22
09	Ward Cr	6	37	16
St. Regis HUC 5		**124**	**846**	**15**

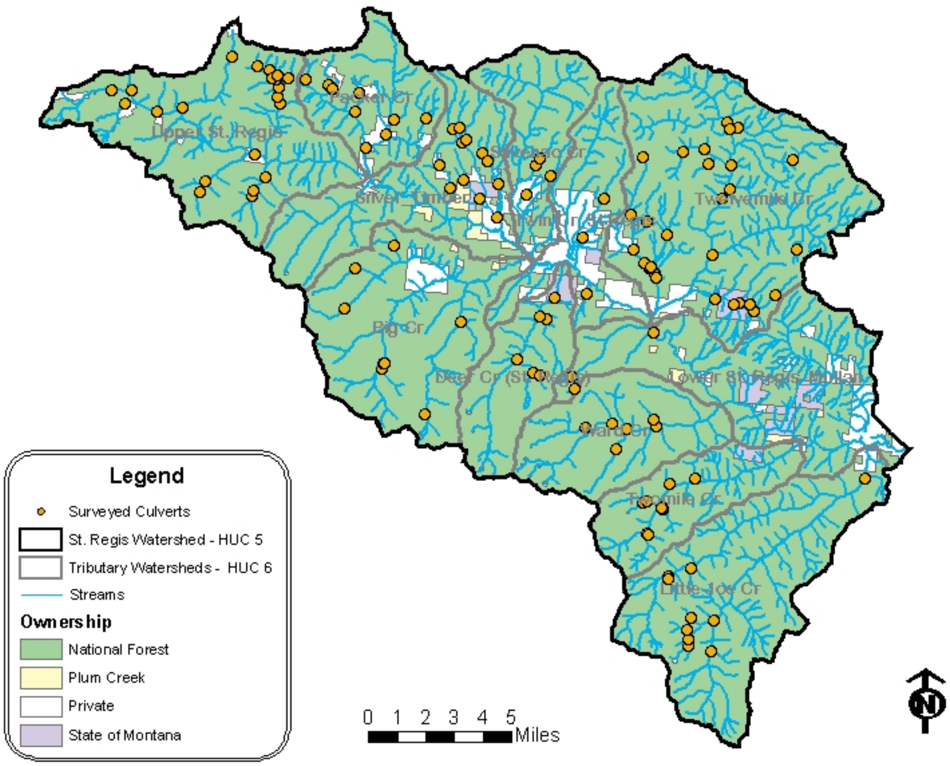

Figure J-1. Stream crossing culverts on fish-bearing streams in St. Regis watershed surveyed in 2002 as part of culvert fish passage analysis

The culvert fish passage analysis revealed that almost all of the culverts surveyed span less than the bankfull width of the streams they cross. This relationship is expressed as a ratio of culvert width to bankfull width, also known as constriction ratio. Ninety-eight percent of culverts surveyed have a constriction ratio less than 1.0 (**Figure J-2**).

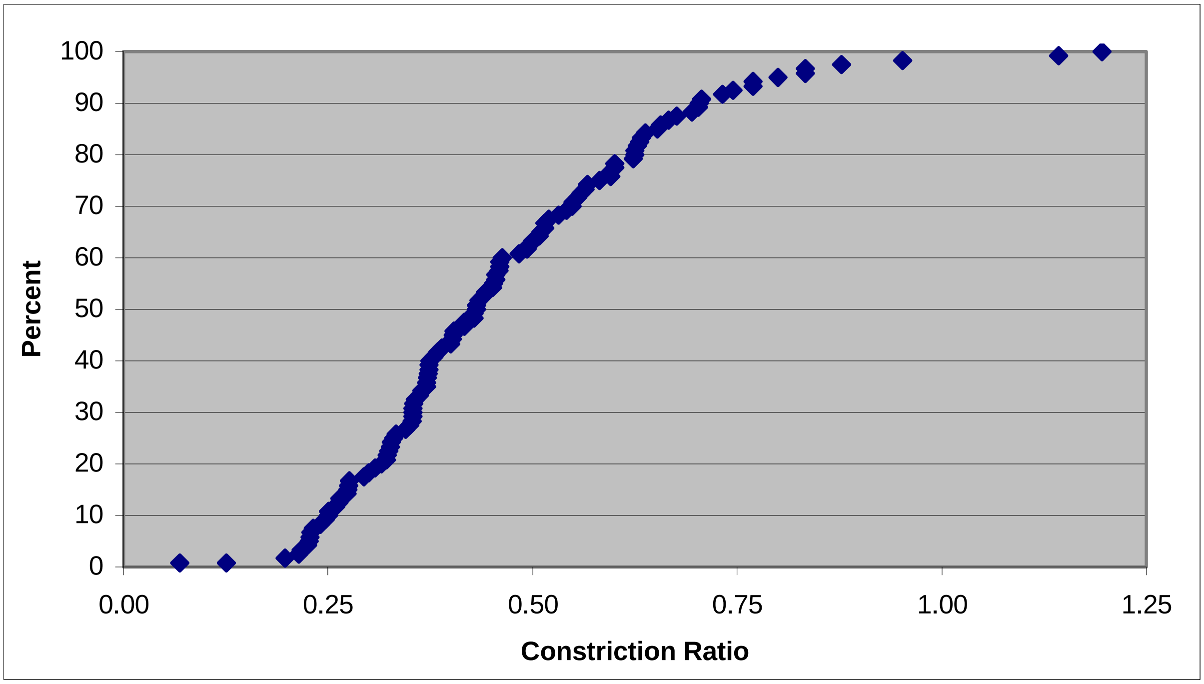

Figure J-2. Cumulative percent distribution of constriction ratio for culverts on fish-bearing streams in the St. Regis watershed

The ability of fish to pass through a culvert with a corrugated bottom is limited, especially when the constriction ratio is less than one. Fish passage capabilities of 119 culverts were evaluated by modeling with the culvert survey data using Region 1 Fish Passage Evaluation Criteria. Based on analysis of the culvert survey data, 3 (2.5%) of these culverts allow for passage of both adult and juvenile fish, while 103 (86.6%) pass neither adult nor juvenile fish. For the remaining 13 culverts (10.9%), passage is possible by at least adult fish or juvenile fish but is not determined for the other category (5 culverts), or passage is not determined for both categories (8 culverts). (**Table J-2** and **Figure J-3**).

Table J-2. Fish passage capability results

		Juvenile Fish Passage			
		Green	**Natural Simulation**	**Grey**	**Red**
Adult Fish Passage	Green	2	0	1	0
	Natural Simulation	0	1	0	0
	Grey	0	0	8	4
	Red	0	0	0	103

Green = hydraulically possible, **Natural Simulation** = conditions are natural (bridge or bottomless arch); passage is possible, **Grey** = too close to call by hydraulic calculations, **Red** = hydraulically impossible

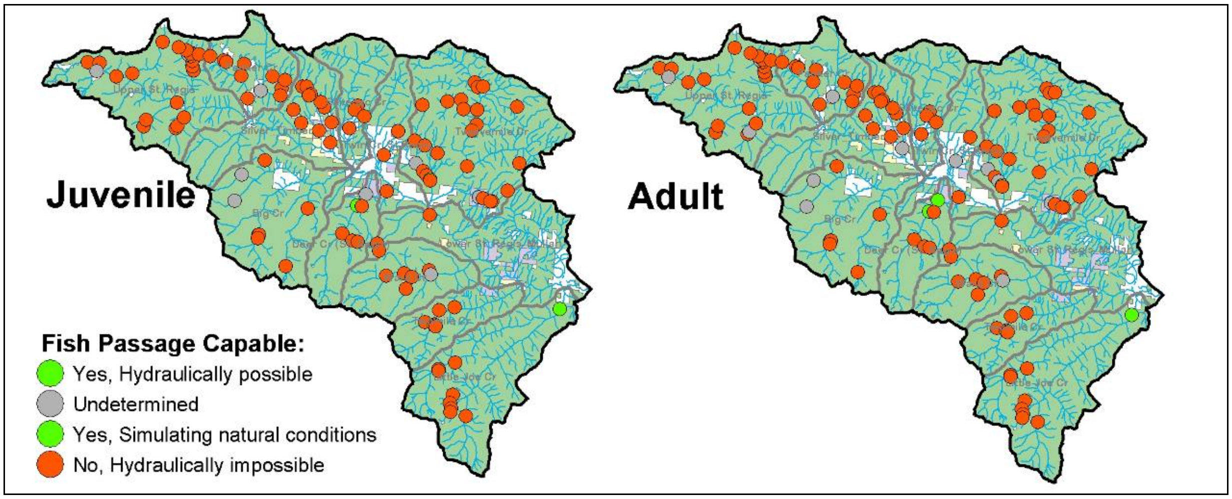

Figure J-3. Map of fish passage capabilities of surveyed culverts in the St. Regis watershed

Not only are undersized culverts often incapable of fish passage, they are also susceptible to failure or blow-out due to the ponding or bottleneck of water at the culvert inlet. Culvert failure results in direct contribution of road fill material to the stream. This study determined the road fill volume subject to erosion and direct delivery from culvert failure. Modeled discharge and associated headwater depth to culvert depth ratio (Hw:D) was used to assess culvert flow capacities and failure risk.

The total volume of potential sediment contribution associated with failure of culverts incapable of passing modeled flows was then summarized. Total road fill failure is not always the response to ponded water at the inlet of undersized culverts. In some instances, only part of the road fill may be contributed to the stream as a result of culvert failure. In other cases, culvert failure occurs when ponded water overflows onto the road causing erosion of the road surface.

Methods

The magnitude of peak discharge (Q) for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals was modeled for each surveyed stream crossing culvert using regression equations developed by Omang (1992). Independent variables in the equations are drainage area (square miles) and mean annual precipitation (inches). Drainage area above each stream crossing was determined using a digital elevation model (DEM) in ArcMap 8.1 Hydrology Tools (ESRI, 2001). Mean annual precipitation for the area drained by each surveyed stream crossing culvert was derived from a GIS raster layer of precipitation (Daly and Taylor, 1998).

Headwater depths (Hw, depth of water ponded at culvert inlet) were determined using software from the US Department of Transportation, Federal Highway Administration (FHWA). The program HDS5eq.exe was downloaded from FHWA’s Hydraulic Engineering Software Archive website (FHWA, 2001). HDS5eq.exe is a nomograph calculator for FHWA “Hydraulic Design of Highway Culverts” (HDS-5) which uses the nomograph charts in HDS-5 Appendix D and inlet control equations found in HDS-5 Appendix A. Based on culvert material, shape, mitering, height, width, discharge, and/or culvert slope, the headwater depth of each culvert was calculated for each modeled discharge.

Analysis of sediment risk from culvert failure was completed for 119 of the surveyed culverts. (Due to incomplete data, 5 of the 124 surveyed culverts could not be included in the sediment risk analysis). Modeled discharge, headwater depth to culvert depth ratio (Hw:D), and road fill volume subject to erosion should culvert failure occur, assuming culvert failure results in 100% delivery of affected road fill volume to the stream were evaluated to determine sediment risk. If the Hw:D exceeded the recommended Hw:D for a given modeled Q at a particular culvert, the associated road fill volume estimate was counted as a potential sediment contribution. Culverts with Hw:D greater than 1.0 (ponding to the top of the culvert inlet) are considered at risk of failure due to the forces of ponded water at the culvert inlet. Culvert failure does not occur every time Hw:D exceeds 1.0. However, corrugated steel pipe manufacturers recommend a Hw:D maximum of 1.5 (ponding 50% above the top of the culvert), and if at all possible less than or equal to 1.0 (American Iron and Steel Institute, 1994). In this analysis, a maximum Hw:D of 1.4 was considered, in addition to Hw:D 1.0. At the Hw:D = 1.0 level, culverts capable of passing a given discharge without exceeding Hw:D = 1.0 were considered not at risk to failure and therefore the potential sediment contribution was 0. All culverts were evaluated similarly at the Hw:D = 1.4 level.

Results

As modeled discharge increases, so does the number of culverts incapable of passing the greater discharges. Ninety-seven percent of the surveyed culverts evaluated are capable of passing the Q2 discharge with a Hw:D less than 1.4 and 1.0, while 43% cannot pass Q100 with Hw:D less than 1.0 and 29% cannot pass Q100 with Hw:D less than 1.4 (**Table J-3** and **Figure J-4**). The number of culverts capable of passing flows at Hw:D < 1.0 is always less than (or equal to in the case of Q2) the number of culverts capable of passing flows at Hw:D < 1.4.

Table J-3. Percent of culverts surveyed capable of passing flows with Hw:D≤1.0 and 1.4

	Hw:Depth	
	1	**1.4**
Q2	97%	97%
Q5	87	95
Q10	81	87
Q25	72	83
Q50	66	79
Q100	57	71

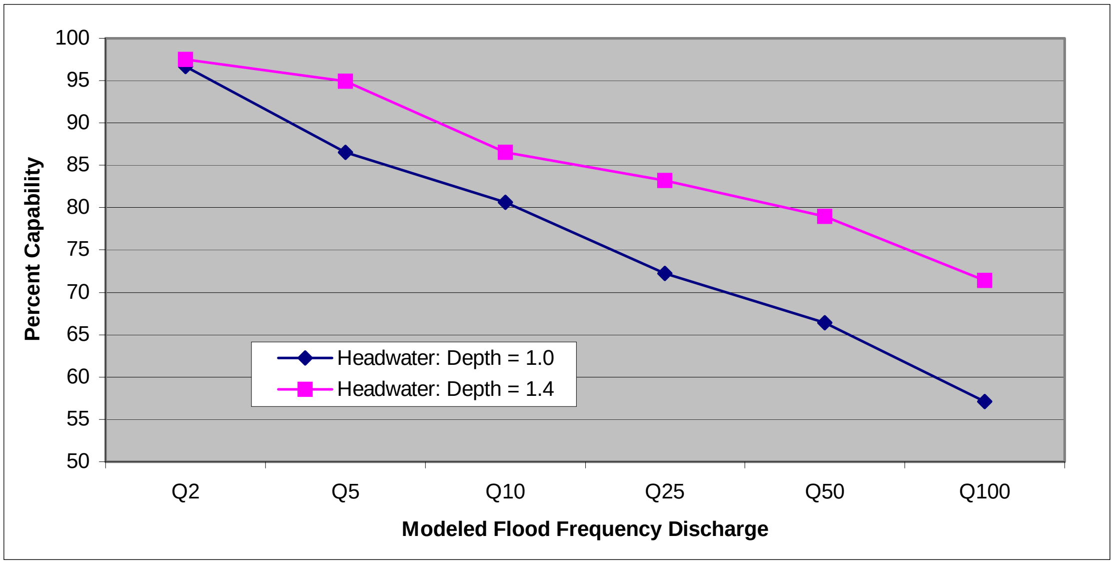

Figure J-4. Percent of culverts surveyed capable of passing flows

Potential sediment associated with culvert failure was summarized by HUC 6 under each modeled discharge / headwater to depth ratio combination (**Table J-4**). For the St. Regis HUC 5, total potential sediment ranges from 96 tons for Q2 and Hw:D = 1.4 to 5283 tons for Q100 and Hw:D 1.0.

Among the HUC 6 tributary watersheds, distribution of potential sediment from culvert failure is not directly related to the distribution of culverts surveyed. Ten and a half percent of the culverts surveyed are located in the Silver-Timber HUC 6 (**Figure J-5**), and account for 73% of the potential sediment from culvert failures in the St. Regis HUC 5 at Q2 and Hw:D = 1.0 (**Figure J-6**). The remaining potential sediment from culvert failures at Q2 flows is in the Upper St. Regis HUC 6 (20% of total potential sediment) and the Twelvemile HUC 6 (7% of total potential sediment).

For modeled Q25 flows and Hw:D 1.0, 52% of the total potential sediment from culvert failures is in the Little Joe HUC 6 representing 9% of the surveyed culverts, and 12% is in the Silver-Timber HUC 6 representing 10.5% of surveyed culverts. The remaining 36% of total potential sediment comes from 80.5% of the surveyed culverts in other tributary watersheds, with proportions ranging from 1 to 7% of the total potential sediment for the St. Regis HUC 5.

Nine percent of the culverts surveyed are located in the Little Joe HUC 6, and account for 34% of the total potential sediment contribution from culvert failures at Q100 and Hw:D 1.0. Forty and a half percent of surveyed culverts are located in Silver-Timber, Twelvemile, and Big Creek tributary watersheds and account for 13% each of total potential sediment. The remaining 27% of total potential sediment is from culvert failures in the other tributary watersheds, with potential sediment proportions ranging from 1 to 7%.

Table J-4. Potential sediment contribution (road fill estimate, tons) at risk from culvert failures based on modeled discharge and headwater depth to culvert depth ratio

	Q2		Q5		Q10		Q25		Q50		Q100	
Headwater: Depth	**1.0**	**1.4**	**1.0**	**1.4**	**1.0**	**1.4**	**1.0**	**1.4**	**1.0**	**1.4**	**1.0**	**1.4**
Big Creek	0	0	109	0	197	109	197	197	197	197	679	197
Deer Creek	0	0	0	0	42	0	121	42	375	121	375	121
Little Joe Creek	0	0	53	0	291	53	1664	291	1664	291	1815	1548
Lower St. Regis	0	0	126	0	126	126	126	126	126	126	126	126
Packer Creek	0	0	29	0	29	29	29	29	194	29	194	29
Savenac Creek	0	0	0	0	0	0	15	0	49	0	49	49
Silver Timber	87	65	198	87	198	198	379	198	637	198	702	379
Twelvemile	8	8	154	100	199	154	201	180	353	198	697	220
Twin Creek	0	0	0	0	0	0	0	0	77	0	77	0
Two Mile Creek	0	0	0	0	66	0	103	0	103	103	103	103
Upper St. Regis	23	23	23	23	136	23	136	23	136	136	255	136
Ward Creek	0	0	0	0	0	0	213	0	213	0	213	213
St. Regis	118	96	692	209	1284	692	3183	1086	4124	1398	5283	3120

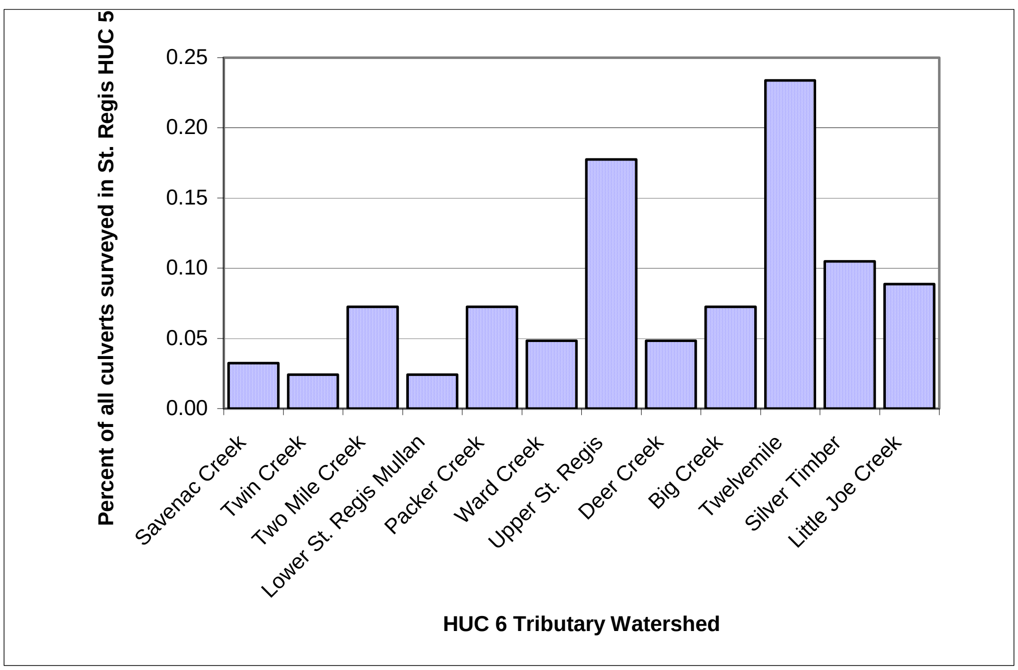

Figure J-5. Distribution among HUC 5 tributary watersheds of all culverts surveyed in the St. Regis River HUC 5

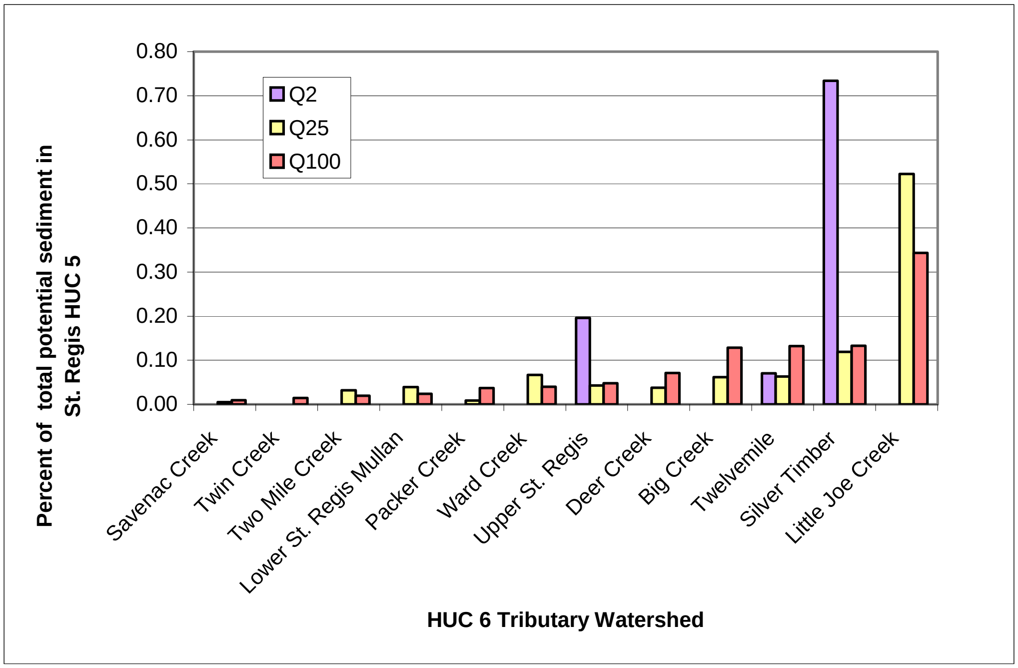

Figure J-6. Summary of potential sediment contribution from culverts at-risk of failure under Hw:D 1.0 condition

Estimating potential sediment contribution from culvert failure involved determining how much sediment is produced in a century based on probability of flood recurrence and sediment produced by each flood size and averaging the century loads to provide the potential yearly estimated load. A headwater depth to culvert depth ratio of 1 was used in this analysis. Also, all of the fill at a crossing will not fail. An estimated 20% of an average culvert stream crossing was likely to fail in the St. Regis Watershed. The existing culvert failure rate scenario assumes that culverts will be replaced with the same sized culverts that failed (**Table J-5**). Next, the sediment yields from the monitored locations were extrapolated to the watershed scale using GIS analysis. Culvert failure modeling scenarios were completed to assist in TMDL allocations (**Table J-5**). Two scenarios were completed by eliminating failures that are likely to occur with culverts sized to Q50 and Q100 designs. These scenarios would estimate potential sediment yield when all culverts in the watershed were replaced with these sized culverts.

Table J-5. Average annual potential sediment loads from culvert failure and estimated load reductions from mitigation practices

	Existing Total Average Annual Sediment Yield Potential (t/Y)	Total Average Annual Yield Potential (t/Y) for Q50 upgrade	% Reduction due to Q50 upgrades	Total Average Annual Yield Potential (t/Y) for Q100 upgrade	% Reduction due to Q100 upgrades
Big Creek	65.46	11.68	82	7.4	89
Deer Creek	10.82	6	45	2	82
Little Joe Creek	344.06	112.22	67	39.6	88
Lower St. Regis	494.18	40.06	92	13.36	97
Packer Creek	18.82	6.98	63	2.32	88

Table J-5. Average annual potential sediment loads from culvert failure and estimated load reductions from mitigation practices

	Existing Total Average Annual Sediment Yield Potential (t/Y)	Total Average Annual Yield Potential (t/Y) for Q50 upgrade	% Reduction due to Q50 upgrades	Total Average Annual Yield Potential (t/Y) for Q100 upgrade	% Reduction due to Q100 upgrades
Savenac Creek	1.86	1.32	29	0.44	76
Silver Timber	131.46	18.84	86	6.7	95
Twelvemile	87.88	16.06	82	7.98	91
Twin Creek	5.86	5.86	0	1.96	67
Two Mile Creek	14.42	3.22	78	1.08	93
Upper St. Regis	36.74	4.8	87	2.32	94
Ward Creek	18.38	7.88	57	2.62	86
St. Regis	802.92	184.64	77	72.08	91

Discussion

Several approaches may be taken to interpret the results of this analysis and determine how to reduce the risk of potential sediment contribution from culvert failure. One approach is to upgrade culverts incapable of passing the most frequent flows. Risk of culvert failure decreases when culverts are capable of passing the most frequent flows, and when capable of passing larger flows. Another approach is to upgrade those undersized culverts with the greatest amount of road fill at risk of becoming sediment in the event of culvert failure. By ensuring that culverts with the greatest amount of road fill are large enough to pass flows, the quantity of potential sediment decreases. The results of this analysis are based on current conditions and do not factor in potential increased flows after timber harvest or forest fires.

The current sediment load potential from culvert failure will be compared to a road system that can pass 100 year storm events without failure for the allocation approach. This approach is consistent with Forest Service standards (Q100) but should be applied watershed wide, not only on Forest Service lands. See the main document for the allocation approach to sediment due to risk of culvert failure.

Several caveats should be considered when interpreting the results of this analysis. First, the USGS regression equations are subject to large standard errors that at times can substantially over or under predict discharge. Second, the assessment was conducted using a sub-sample of approximately 20% of culverts in the St. Regis watershed. Also important to consider is the short-term sediment contribution that results from disturbing the existing roadbed to remove and replace undersized culverts with larger culverts. Based on previous Lolo National Forest Monitoring Reports and other research the short-term sediment pulse is expected to be about 2 tons per culvert during the first 24 hours during and after culvert replacement (USDA, 1999). Most of the sediment increases passes within 24 hours, and decays to near normal levels within one year. Mitigation measures such as diverting live water, using filter cloths, slash filter windrows, and straw bales, and seeding and fertilizing can reduce this sediment increase up to 80 percent (Wasniewski, 1994).

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